

## S P E C I F I C A T I O N

Docket No. **BA-00586**

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, **Bin Li**, a citizen of Canada, **Kenneth R. Knowles** and **David C. Lawson**, both citizens of the United States of America, all residing in the State of Virginia, have invented new and useful improvements in a

### **CIRCUIT FOR ACCESSING A CHALCOGENIDE MEMORY ARRAY**

of which the following is a specification:

## **BACKGROUND OF THE INVENTION**

The present invention was made under government contract SC-0244-00-

## **1. Technical Field**

The present invention relates to memory circuits in general, and in particular to memory circuits having chalcogenide cells. Still more particularly, the present invention relates to a circuit for accessing a chalcogenide memory array.

## **2. Description of Related Art**

The use of electrically writable and erasable phase change materials for an electronic memory application is known in the art. Such phase change materials can be electrically switched between a first structural state where the material is generally amorphous and a second structural state where the material is generally crystalline. The phase change material exhibits different electrical characteristics depending upon its state. For example, in its amorphous state, the phase change material exhibits a lower electrical conductivity than it does in its crystalline state. The phase change material may also be electrically switched between different detectable states of local order across the entire spectrum ranging from the completely amorphous state to the completely crystalline state. In other words, the state switching of the phase change materials is not limited to either completely amorphous or completely crystalline states but rather in incremental steps to provide a "gray scale" represented by a multiplicity of conditions of local order spanning the spectrum from the completely amorphous state to the completely crystalline state.

General speaking, phase change material memory cells are monolithic, homogeneous, and formed of chalcogenide material containing chemical elements selected

1 from the group of Tellurium (Te), Selenium (Se), Antimony (Sb), Nickel (Ni), and  
2 Germanium (Ge). Chalcogenide memory cells can be switched between two different  
3 electrically detectable states within nanoseconds in response to an input of picojoules of  
4 energy. Chalcogenide memory cells are truly non-volatile and can maintain the stored  
5 information without the need for periodic refreshing. Furthermore, the stored information  
6 remains intact even when power is removed from the chalcogenide memory cells.

7

8           The present disclosure describes a circuit for accessing a chalcogenide  
9 memory array.

## **SUMMARY OF THE INVENTION**

In accordance with a preferred embodiment of the present invention, a random access memory includes a memory array having multiple subarrays with rows and columns formed by chalcogenide storage elements. The random access memory also includes discrete read and write circuits. Associated with a respective one of the subarrays, each of the write circuits includes an independent write 0 circuit and an independent write 1 circuit. Also associated with a respective one of the subarrays, each of the read circuits includes a sense amplifier circuit. In addition, a voltage level control module is coupled to the read and write circuits to ensure that voltages across the chalcogenide storage elements within the memory array do not exceed a predetermined value during read and write operations.

All features and advantages of the present invention will become apparent in the following detailed written description.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

The invention itself, as well as a preferred mode of use, further objects, and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

Figure 1 is a block diagram of a chalcogenide random access memory (CRAM), in accordance with a preferred embodiment of the present invention;

Figure 2 is a block diagram of a column within one of the subarrays within the CRAM from Figure 1, in accordance with a preferred embodiment of the present invention;

Figure 3 is a circuit diagram of a write 0 circuit and a write 1 circuit within the CRAM from Figure 1, in accordance with a preferred embodiment of the present invention;

Figure 4 is a circuit diagram of a post-write discharge circuit within the CRAM from Figure 1, in accordance with a preferred embodiment of the present invention; and

Figure 5 is a circuit diagram of a read voltage clamp circuit within the CRAM from Figure 1, in accordance with a preferred embodiment of the present invention.

1                   **DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT**

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3                   Referring now to the drawings and in particular to Figure 1, there is  
4                   illustrated a block diagram of a chalcogenide random access memory (CRAM), in  
5                   accordance with a preferred embodiment of the present invention. As shown, a CRAM 10  
6                   includes write circuits 15a-15n, read circuits 16a-16n, and memory subarrays 17a-17n.  
7                   Each of memory subarrays 17a-17n is associated with a separate write circuit and a  
8                   separate read circuit. For example, memory subarray 17a is associated with write circuit  
9                   15a and read circuit 16a, memory subarray 17b is associated with write circuit 15b and  
10                  read circuit 16b, memory subarray 17n is associated with write circuit 15n and read circuit  
11                  16n, etc. Write circuits 15a-15n and read circuits 16a-16n are collectively controlled by  
12                  a voltage level control module 11.

13

14                  Voltage level control module 11 includes a post-write discharge circuit 12,  
15                  a read voltage clamp circuit 14 and a reference voltage circuit 13. Reference voltage circuit  
16                  13 provides a constant reference voltage for post-write discharge circuit 12 and read voltage  
17                  clamp circuit 14. In addition, the reference voltage generated by reference voltage circuit  
18                  13 is preferably selected to optimize the clamping voltage generated by read voltage clamp  
19                  circuit 14 in accordance with the processing technology for CRAM 10.

20

21                  CRAM 10 also includes a column decoder 18 and a row decoder 19.  
22                  Column decoder 18 further contains a write logic circuit 91, a read logic circuit 92 and a  
23                  column address circuit 93. During a write operation, write logic circuit 91 provides a  
24                  column address to corresponding write circuits 15a-15n such that data can be written to an  
25                  appropriate column within one of subarrays 17a-17n. During a read operation, read logic  
26                  circuit 92 provides a column address to corresponding read circuits 16a-16n such that data  
27                  can be read from an appropriate column within one of subarrays 17a-17n. In conjunction  
28                  with the column addresses from column decoder 18, row decoder 19 provides row

1        addresses for the appropriate memory cell within subarrays **17a-17n** during read and write  
2        operations.

3  
4        CRAM **10** can be coupled to an electronic device (not shown) such as a  
5        processor, a memory controller, a chip set, etc. The electronic device is preferably coupled  
6        to column decoder **18** and row decoder **19** via respective address lines. The electronic  
7        device is also coupled to voltage level control module **11** via various control lines. In  
8        addition, the electronic device is coupled to an input/output circuit of CRAM **10** via  
9        corresponding input/output lines.

10  
11        Each of write circuits **15a-15n** includes a write 0 circuit and a write 1  
12        circuit. As their names imply, a write 0 circuit is utilized to write a logical "0" to a  
13        memory cell within a corresponding one of subarrays **17a-17n**, and a write 1 circuit is  
14        utilized to write a logical "1" to a memory cell within a corresponding one of subarrays  
15        **17a-17n**. Each of read circuits **16a-16n** includes a sense amplifier circuit. Each of  
16        subarrays **17a-17n** are arranged in columns and rows. Along the sense amplifier circuits,  
17        subarrays **17a-17n** are constructed to use a memory cell sensing scheme such that each  
18        column is to be used in reading data from a memory cell within a corresponding one of  
19        subarrays **17a-17n**.

20  
21        In Figure 1, CRAM **10** is shown to have a single memory array having  
22        multiple subarrays, such as subarrays **17a-17n**. However, a CRAM may have multiple  
23        memory arrays and each of the memory arrays may include multiple subarrays. Although  
24        a CRAM only needs one row multiplexor and one column multiplexor, each memory array  
25        within a CRAM preferably includes one reference voltage circuit, such as reference voltage  
26        circuit **13**. In addition, each subarray is preferably associated with one write 0 circuit, one  
27        write 1 circuit and one read circuit.

With reference now to Figure 2, there is depicted a block diagram of a column within one of subarrays 17a-17n from Figure 1, in accordance with a preferred embodiment of the present invention. Each column within subarrays 17a-17n includes multiple memory cells, and each memory cell is comprised of a storage element made of chalcogenide materials. Chalcogenide materials are chemical elements selected from the group of Tellurium (Te), Selenium (Se), Antimony (Sb) and Germanium (Ge). As shown, a chalcogenide storage element 26 is coupled to a column switch 25 and a row switch 27. Row switch 25 and column switch 27 are part of a row multiplexor and a column multiplexor, respectively.

During a write operation, chalcogenide storage element 26 is accessed by either a write 0 circuit 28 or a write 1 circuit 29, and then by post-write discharge circuit 12. During a read operation, chalcogenide storage element 26 is accessed by read circuit 16a via read voltage clamp circuit 14. The reference voltage for read voltage clamp circuit 14 is provided by reference voltage circuit 13. For the present embodiment, read circuit 16a includes a current mirror 21 and a current-voltage converter 22.

The use of chalcogenide material in a binary mode memory cell requires separate write 0 and write 1 circuits, such as write 0 circuit 28 and write 1 circuit 29, to provide different temperature (energy) profiles based on whether a logical "0" or "1" is to be stored. Each of write circuits 28 and 29 tailors a pulse width to account for the differences in programming time according to the data value needed to be stored in the memory cell. The amount of energy imparted to chalcogenide storage element 26 varies, depending on the desired polycrystalline or amorphous retention state. Upon the receipt of input data, either write 0 circuit 28 or write 1 circuit 29 provides an appropriate amount of current flow to chalcogenide storage element 26. Additional control can be provided through independent bias points that sufficiently modulate write circuits 28 and 29 from an external source.

Referring now to Figure 3, there is depicted a circuit diagram of a write circuit, in accordance with a preferred embodiment of the present invention. As shown, write circuit 15a includes write 0 circuit 28 and write 1 circuit 29. Write 0 circuit 28 includes p-channel transistors 51-52 and n-channel transistor 55. Write 1 circuit 29 includes p-channel transistors 53-54 and n-channel transistor 56. Transistors 51 and 55 are connected in series between power supply  $V_{DD}$  and ground. Similarly, transistors 53 and 56 are connected in series between power supply  $V_{DD}$  and ground. Transistors 52 and 54 are separately connected between power supply  $V_{DD}$  and chalcogenide memory element 26. The gate of transistor 52 is connected to the node between transistors 51 and 55. The gate of transistor 54 is connected to the node between transistors 53 and 56.

Inputs to write circuit 15a include write enable input 65, column decode input 66 and data input 67. An NAND gate 57 combines a write enable signal at write enable input 65, a column decode signal at column decode input 66 and a data signal at data input 67 to feed the gates of transistors 51 and 55. Similarly, an NAND gate 58 combines a write enable signal at write enable input 65, a column decode signal at column decode input 66 and a data signal at data input 67 to feed the gates of transistors 53 and 56.

Transistor 54 is the write transistor for write 0 circuit 28, and transistor 52 is the write transistor for write 1 circuit 29. For the present embodiment, the size of transistor 54 is preferably larger than the size of transistor 52 such that more current can be provided to chalcogenide memory element 26 for a write 0 operation. Incidentally, relatively less current is provided to chalcogenide memory element 26 by transistor 52 for a write 1 operation. Specifically, when the data signal at data input 67 is a logical "0" during a write operation, transistor 54 within write 0 circuit 28 is turned on to allow a first predetermined amount of current to program chalcogenide memory element 26 to store a logical "0." When the data signal at data input 67 is a logical "1" during a write operation,

1 transistor **52** within write 1 circuit **29** is turned on to allow a second predetermined amount  
2 of current to program chalcogenide memory element **26** to store a logical "1."  
3

4 Post-write discharge circuit **12** (from Figure 1) is specifically designed to  
5 lower the voltage on a previously written column to prevent any reprogramming of a  
6 chalcogenide storage element within the same column on subsequent read operations. With  
7 reference now to Figure 4, there is illustrated a circuit diagram of post-write discharge  
8 circuit **12**, in accordance with a preferred embodiment of the present invention. As shown,  
9 post-write discharge circuit **12** includes an n-channel transistor **31** and an n-channel  
10 transistor **32** connected in series. The drain of transistor **31** is connected to chalcogenide  
11 memory element **26**. The source of transistor **31** is connected to the drain of transistor **32**.  
12 The drain of transistor **32** is also connected the gate of transistor **32** to form a diode. The  
13 source of transistor **32** is connected to the ground. With the diode configuration of  
14 transistor **32**, voltage developed across chalcogenide memory element **26** is reduced to  
15 ground plus  $V_t$  as the write cycle terminates. Discharging the node between transistors **31**  
16 and **32** prevents any possible reprogramming of chalcogenide memory element **26** on  
17 subsequent read operations. A discharge signal at a discharge signal input **34** and a column  
18 decode signal at a column decode signal input **35** enable transistor **31** to be connected to  
19 chalcogenide memory element **26** and also enable transistor **31** to be in series with  
20 transistor **32** connected to ground.  
21

22 Read voltage clamp circuit **14** (from Figure 1) establishes an acceptable  
23 voltage limit across chalcogenide memory element **26** to prevent the parasitic effects of  
24 stored charges on a column from influencing the information stored in chalcogenide  
25 memory element **26**. If the column discharges to ground (below the limit set by discharge  
26 circuit **12**), read voltage clamp circuit **24** also restores the voltage of the column to the  
27 acceptable voltage. Referring now to Figure 5, there is depicted a circuit diagram of read  
28 voltage clamp circuit **14**, in accordance with a preferred embodiment of the present  
29 invention. As shown, read voltage clamp circuit **24** includes a p-channel transistor **41** and

1       two n-channel transistors **42-43** connected in series. The drain of transistor **41** is connected  
2       to a power supply  $V_{DD}$ . The source of transistor **43** is connected to chalcogenide memory  
3       element **26**. The gate of transistor **41** is connected to an NAND gate **44** having a negative  
4       clock signal input **47** and a column decode input **48**. The gate of transistor **42** is connected  
5       to a voltage limit signal input **45**. The gate of transistor **43** is connected to a read signal  
6       input **46**. A voltage limit signal from voltage limit signal input **45** modulates the  
7       acceptable voltage during the negative clock cycle.

8  
9                  As has been described, the present invention provides a circuit for accessing  
10       a chalcogenide memory array. Although only one chalcogenide storage element is utilized  
11       to illustrate the present invention, it is understood by those skilled in the art that two  
12       chalcogenide storage elements can be associated with a logical data bit by utilizing a  
13       double-ended or "differential" version of the above-described single-ended circuit. The  
14       doubled-end circuit is similar to the above-described single-ended circuit except that there  
15       is a complementary data input with its own read and write circuits to store the complement  
16       of each input data bit in a chalcogenide storage element, and a differential amplifier circuit  
17       is utilized to sense the complementary data bits stored. The differential design of the true-  
18       and-complement value of each logical data bit provides a higher noise margin and thus  
19       provides a greater reliability for each data bit stored in case of a defect exists in the input  
20       signals or the chalcogenide memory chip.

21  
22                  While the invention has been particularly shown and described with reference  
23       to a preferred embodiment, it will be understood by those skilled in the art that various  
24       changes in form and detail may be made therein without departing from the spirit and scope  
25       of the invention.